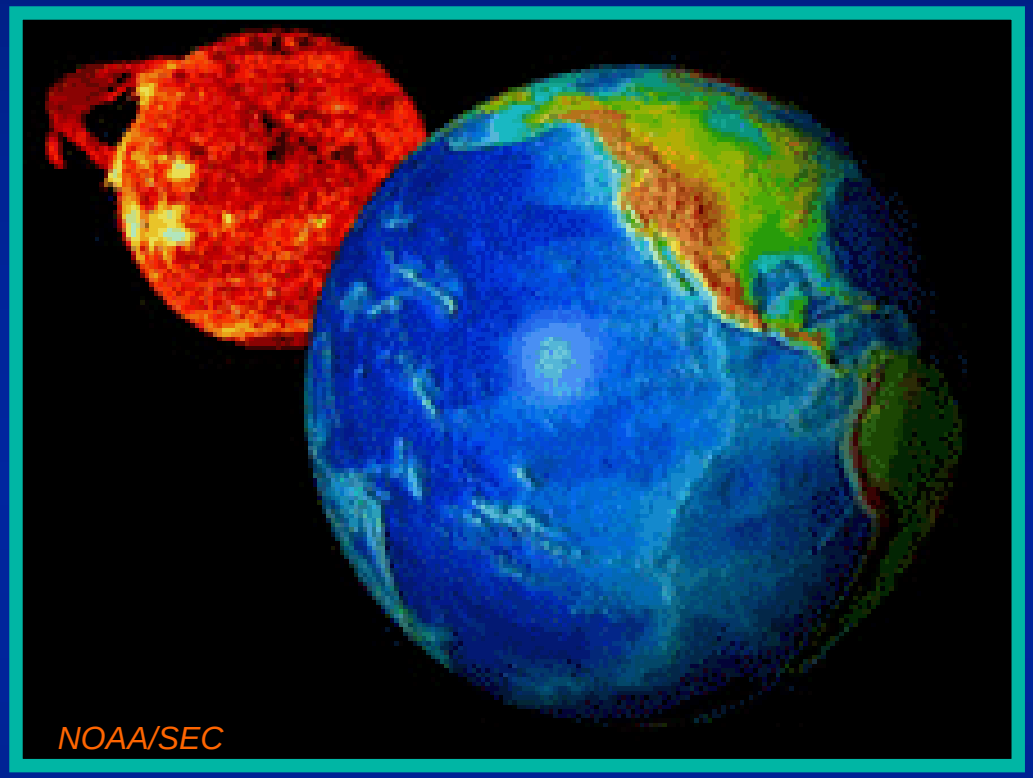
Recent Progress in Space Radiation Environment Models



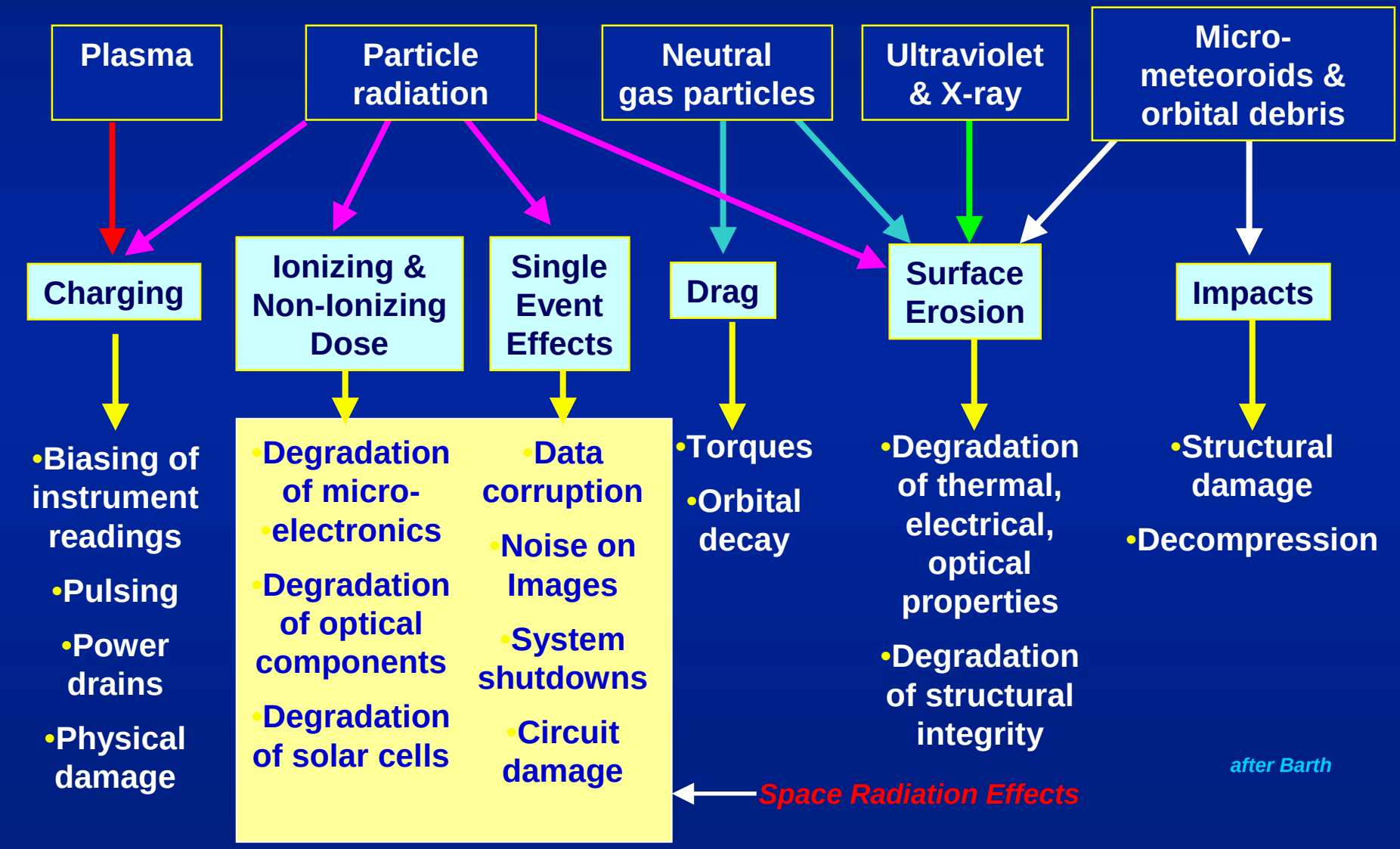
Michael Xapsos and Janet Barth

NASA/Goddard Space Flight Center

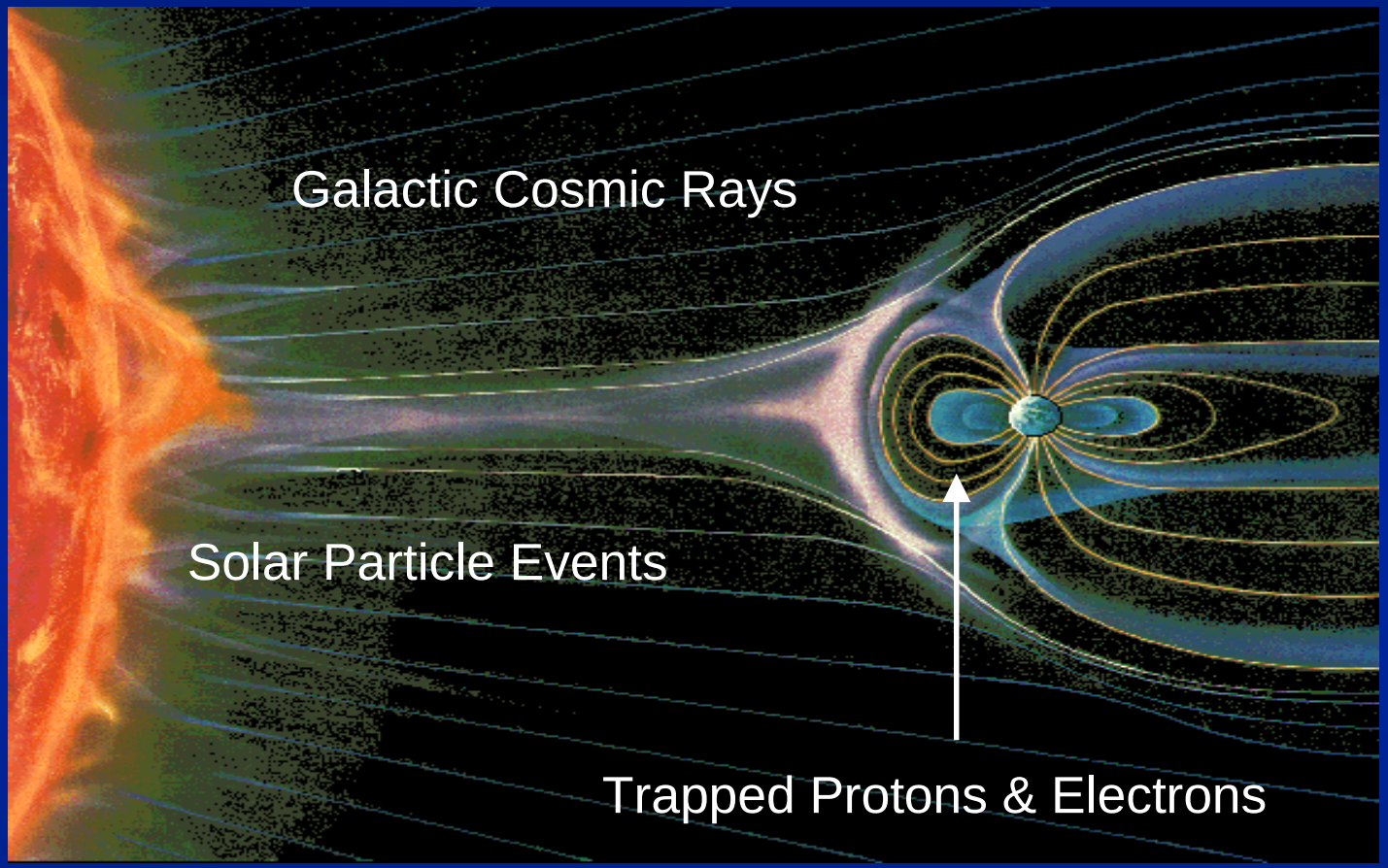
Jean-Marie Lauenstein

Muniz Engineering, Inc.

Environments and Effects Overview

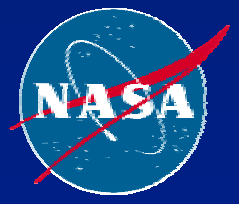


High Energy Radiation Particles



Deep space missions may also see neutrons from planetary background and other trapped particle belts.

Earth's atmospheric and terrestrial radiation includes secondary particles such as neutrons produced by GCR and solar particles.

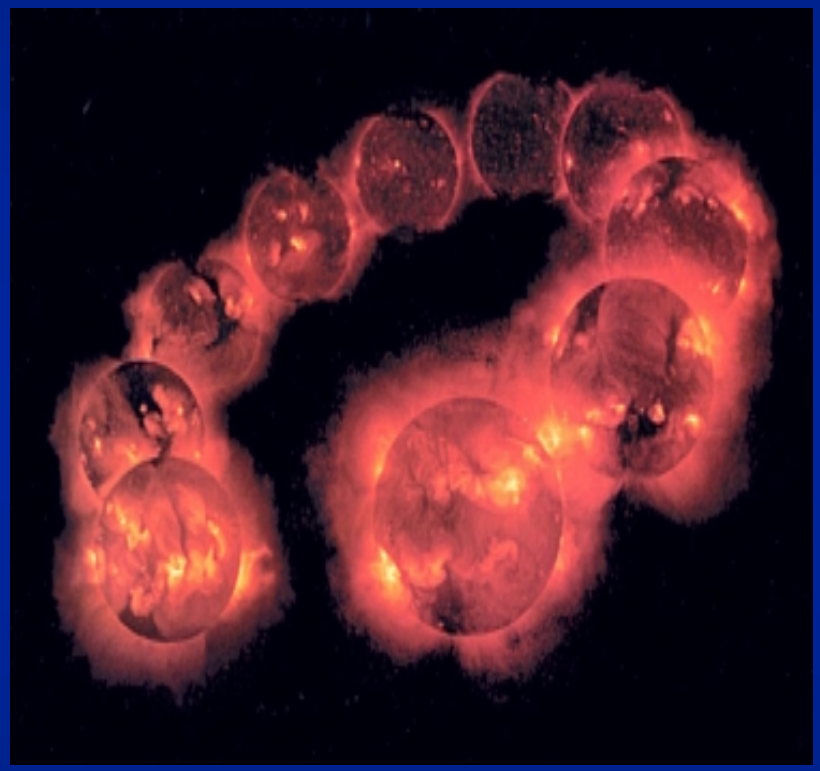


Outline

- Background - Solar Activity Cycle
- Solar Particle Events
- Galactic Cosmic Rays (GCR)
- Trapped Particles
- Displacement Damage Models for Solar Cells
- Summary

The Solar Activity Cycle

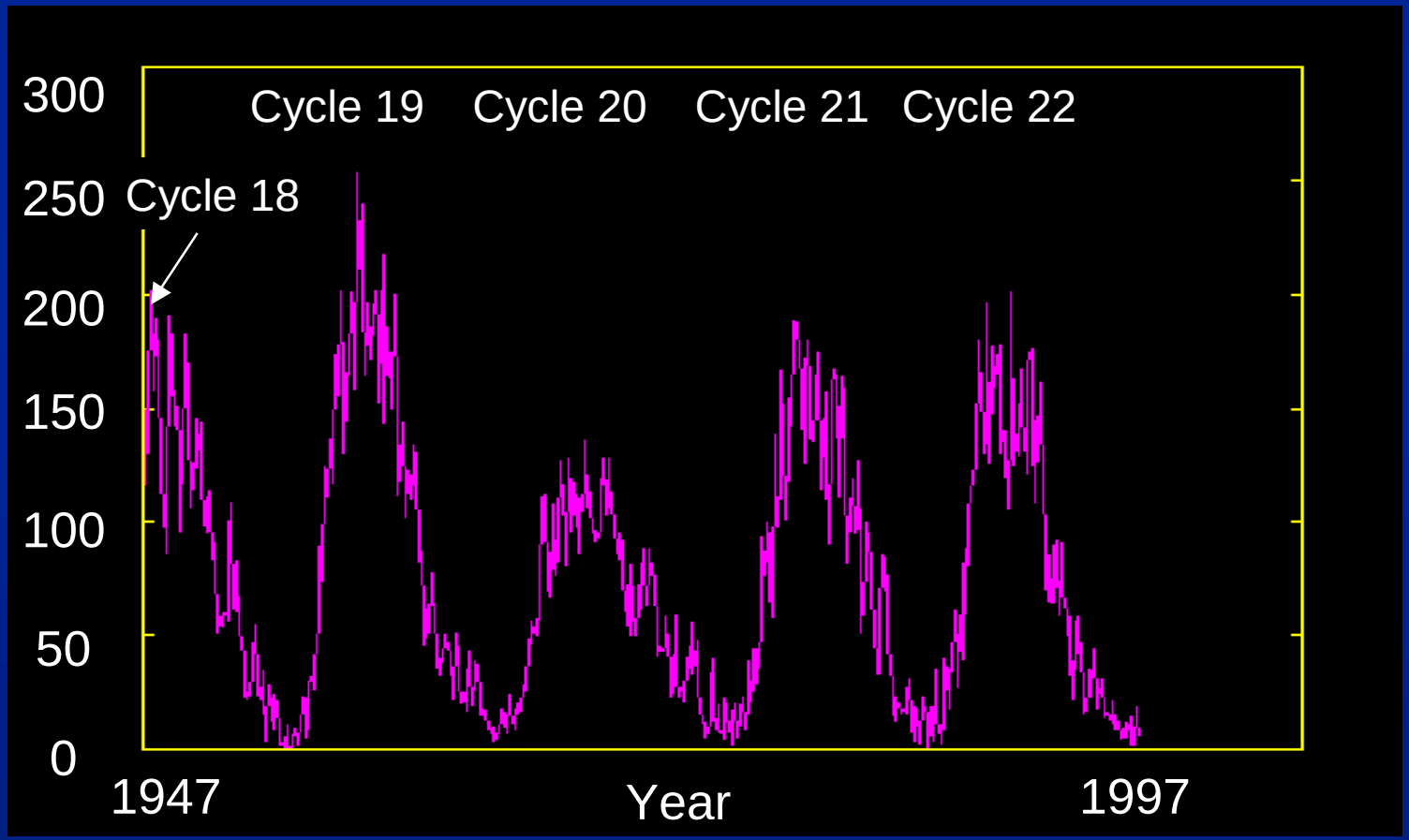
- Solar cycle is typically 11 years:
  - Solar Maximum (7 years)
  - Solar Minimum (4 years)
- Solar particle event, galactic cosmic ray and trapped particle fluxes all vary throughout cycle.



The Solar Activity Cycle

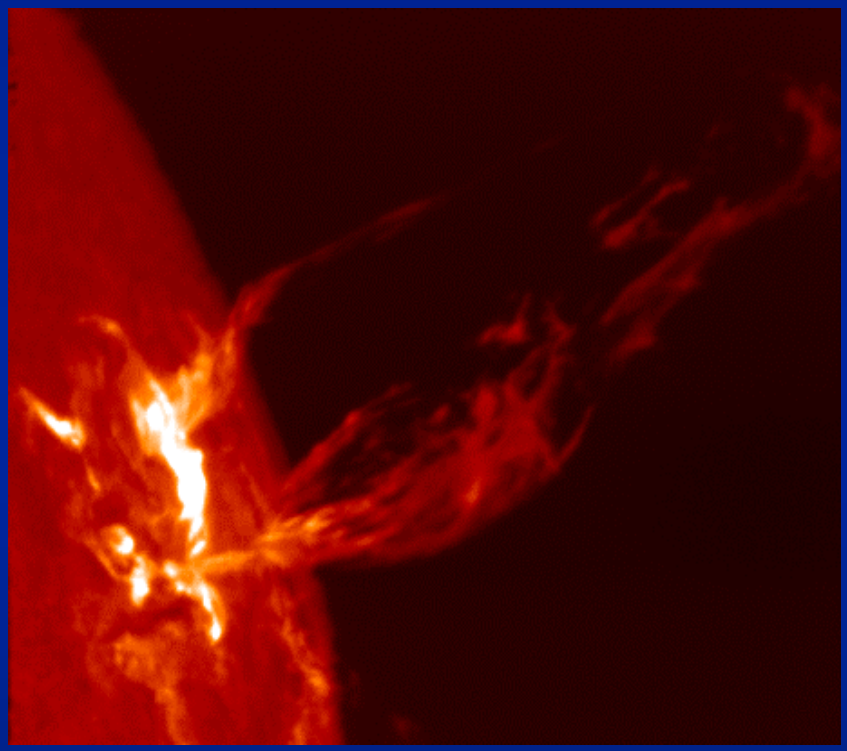
- **Common indicators of solar activity:**
  - **Sunspot numbers**
  - **10.7 cm radio flux**

after Lund Observatory



Solar Particle Events

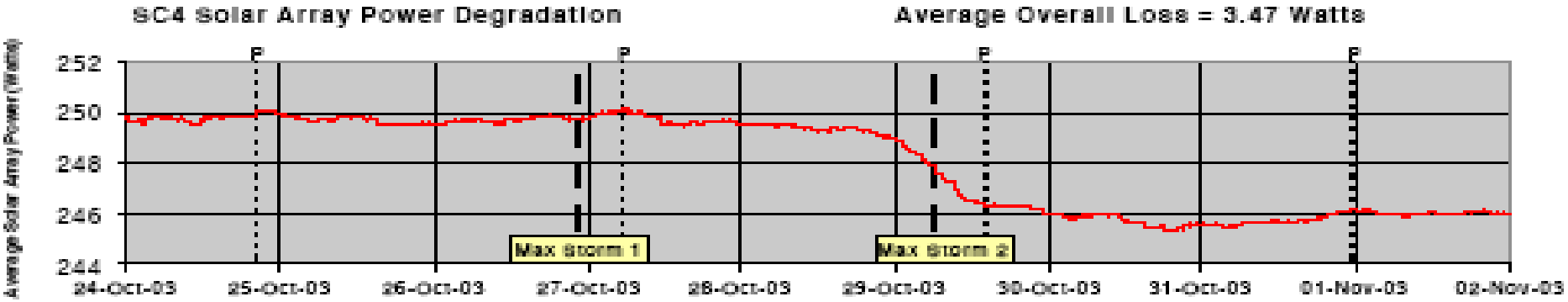
- Occur randomly in time, more frequently during solar maximum
- Event sizes span orders of magnitude; generally larger during solar maximum
- Radiation consists of protons, heavy ions, electrons, x-rays,…
- Particle energies up to ~GeV/n
- Duration: hours to days
- Large events may have:
  - Integral fluence > 10^{9} cm^{-2}
  - Ionizing dose > 1 krad(Si)
  - Damage equivalence > 10^{13} 1 MeV electrons / cm^{2}



Solar Array Power Degradation from "Halloween Event" 2003

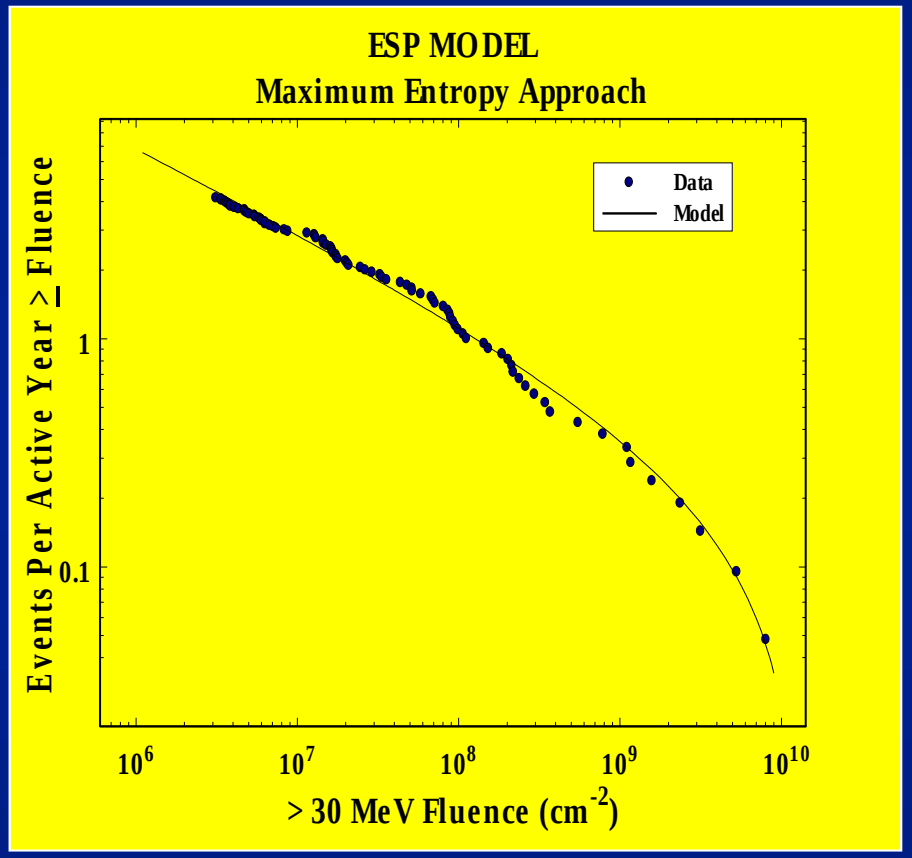
1.4% average power loss on CLUSTER spacecraft

ANNEX 1: Evolution of the Solar Array Power from 24-Oct to 02-Nov 2003 when two solar radiation storms occurred (the time of their maximum is indicated in the plot "---"). The degradation of the panels was about 1.4% and the average power loss is shown for each spacecraft.
The perigee passes are marked as "....." and labeled with "P"



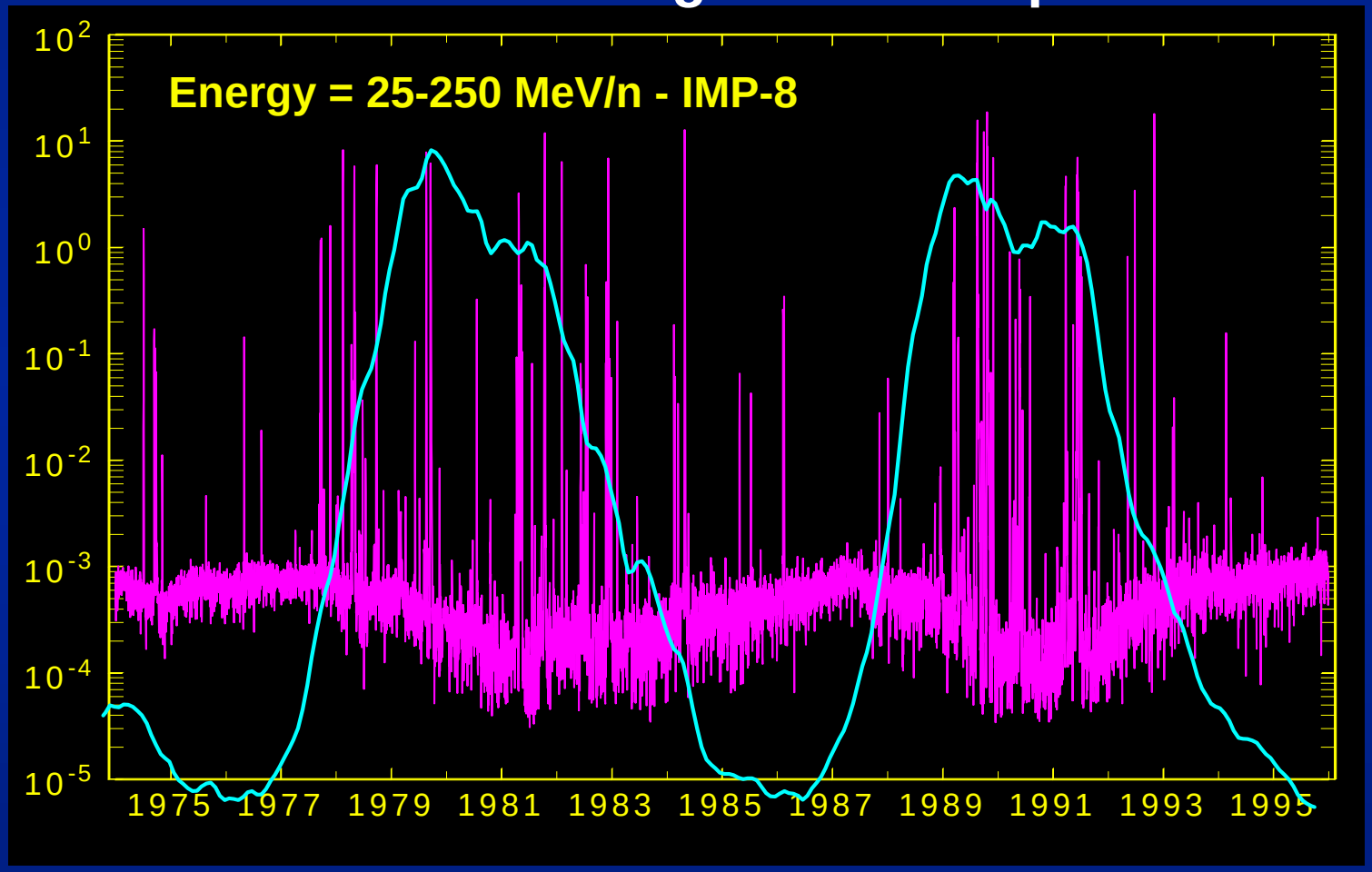
Solar Proton Event Models

- Predict proton fluences during solar max for given confidence level and mission duration
  - » King/Stassinopoulos
  - » JPL91
  - » NASA ESP
    - Based on cycles 20-22
    - 1-300 MeV protons
    - Describes complete range of event sizes
  - » NASA PSYCHIC
    - Continuation of ESP to include solar min, arbitrary orbits, heavy ions; available this year

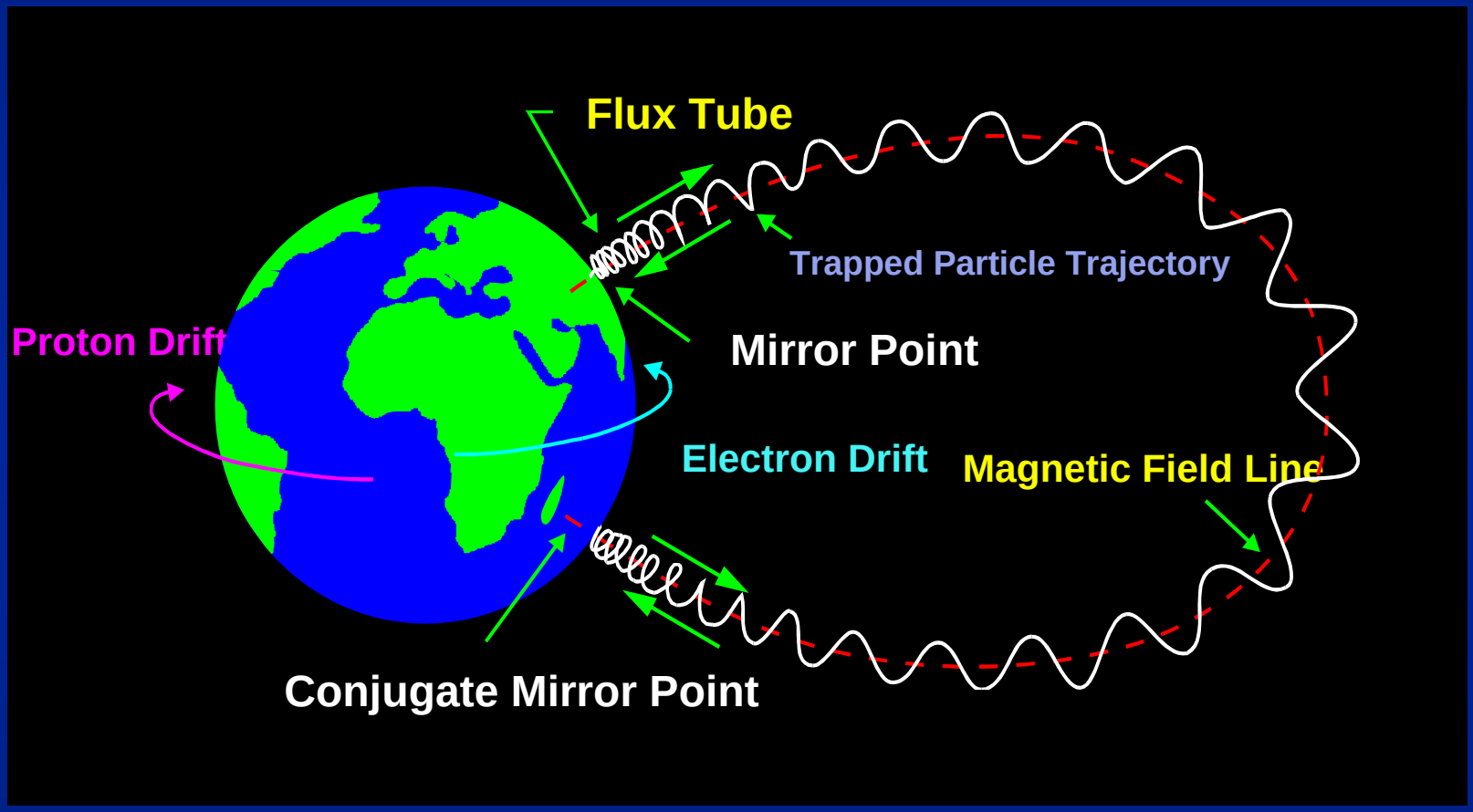


Galactic Cosmic Rays

CNO - 24 Hour Averaged Mean Exposure Flux



Trapped Particles

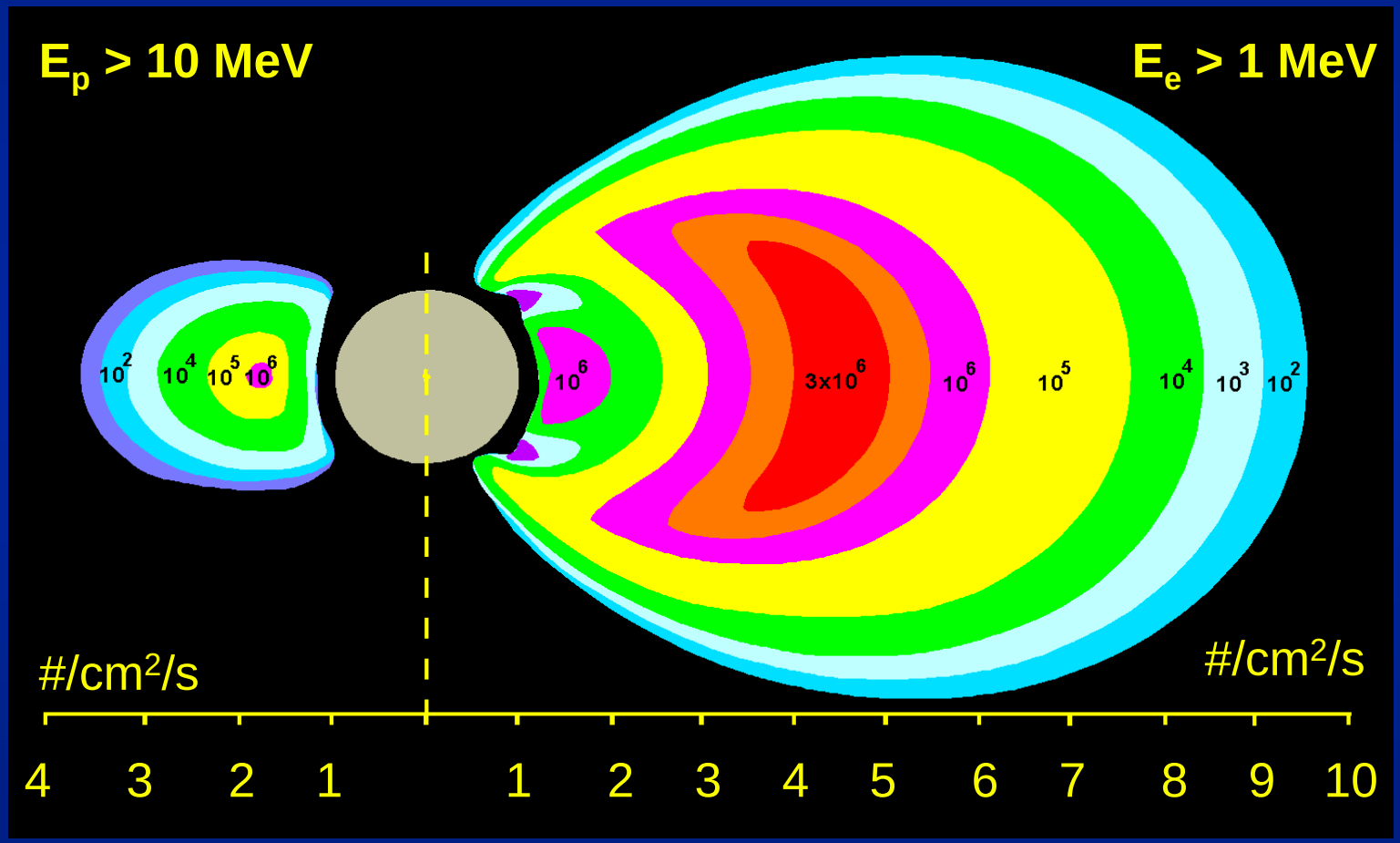


after Hess

Proton & Electron Intensities

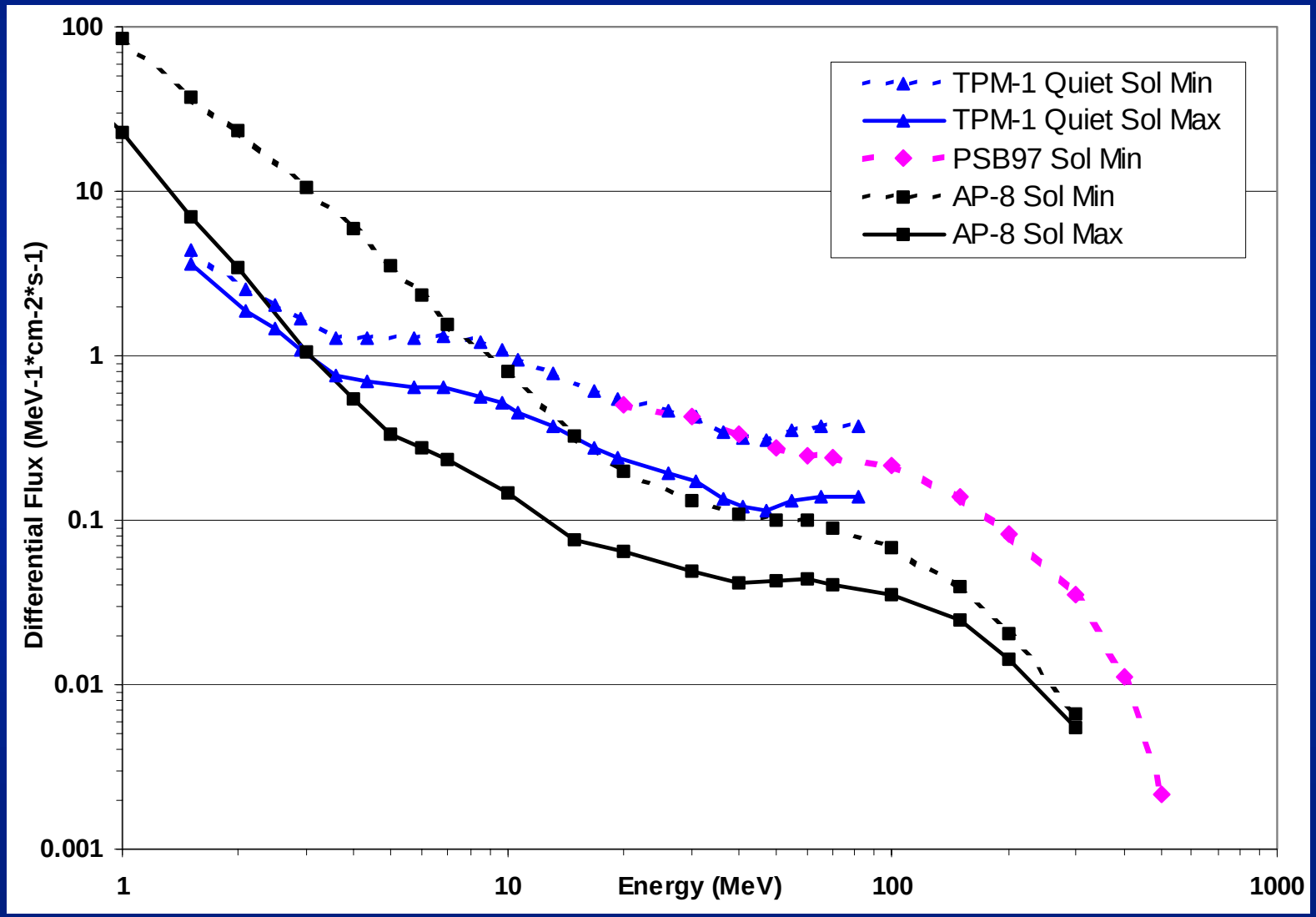
AP-8 Model

AE-8 Model

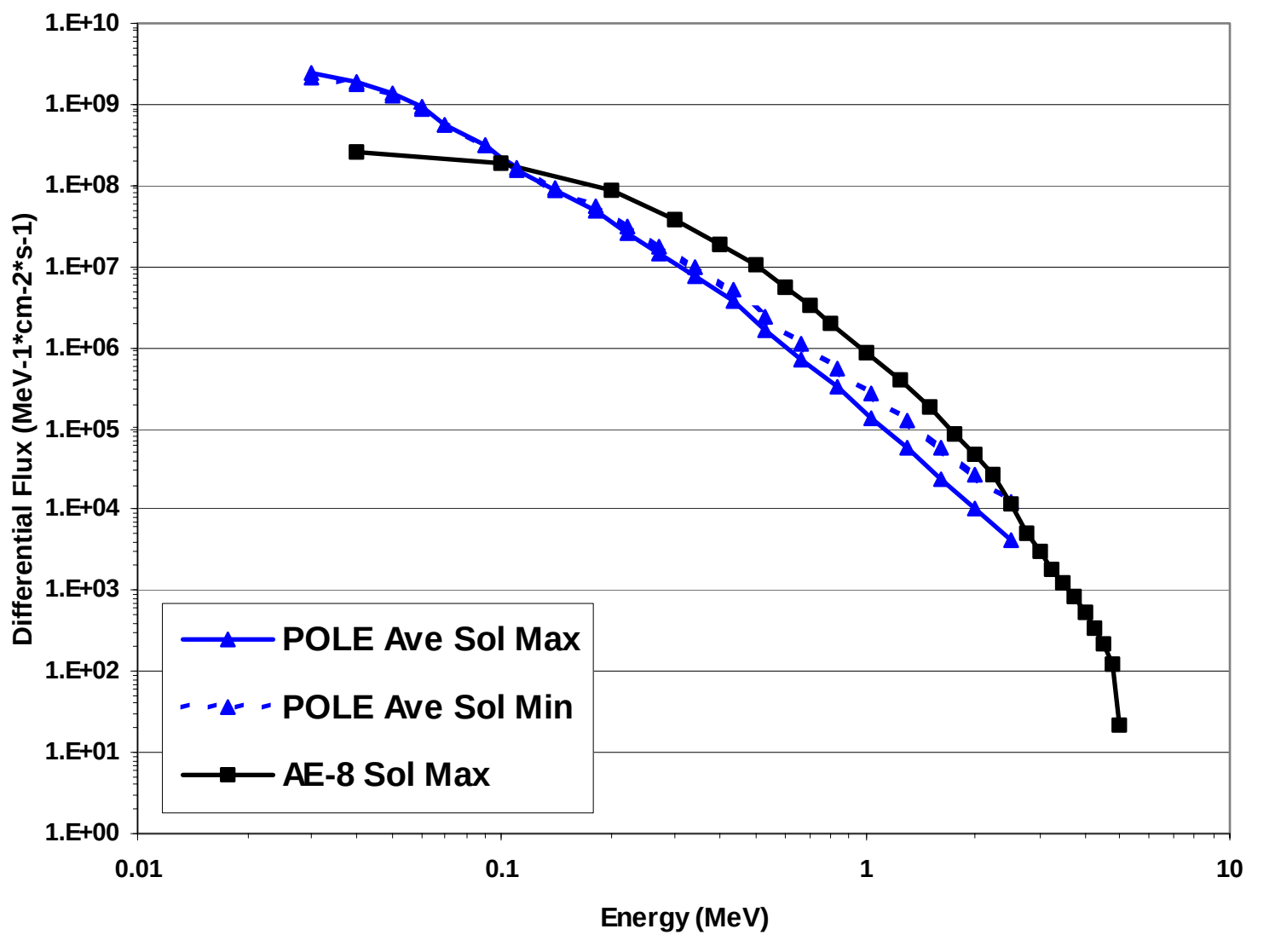


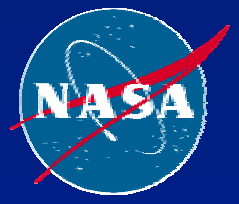
NASA/GSFC

Recent Developments in Trapped Proton Models



Recent Developments in Trapped Electron Models

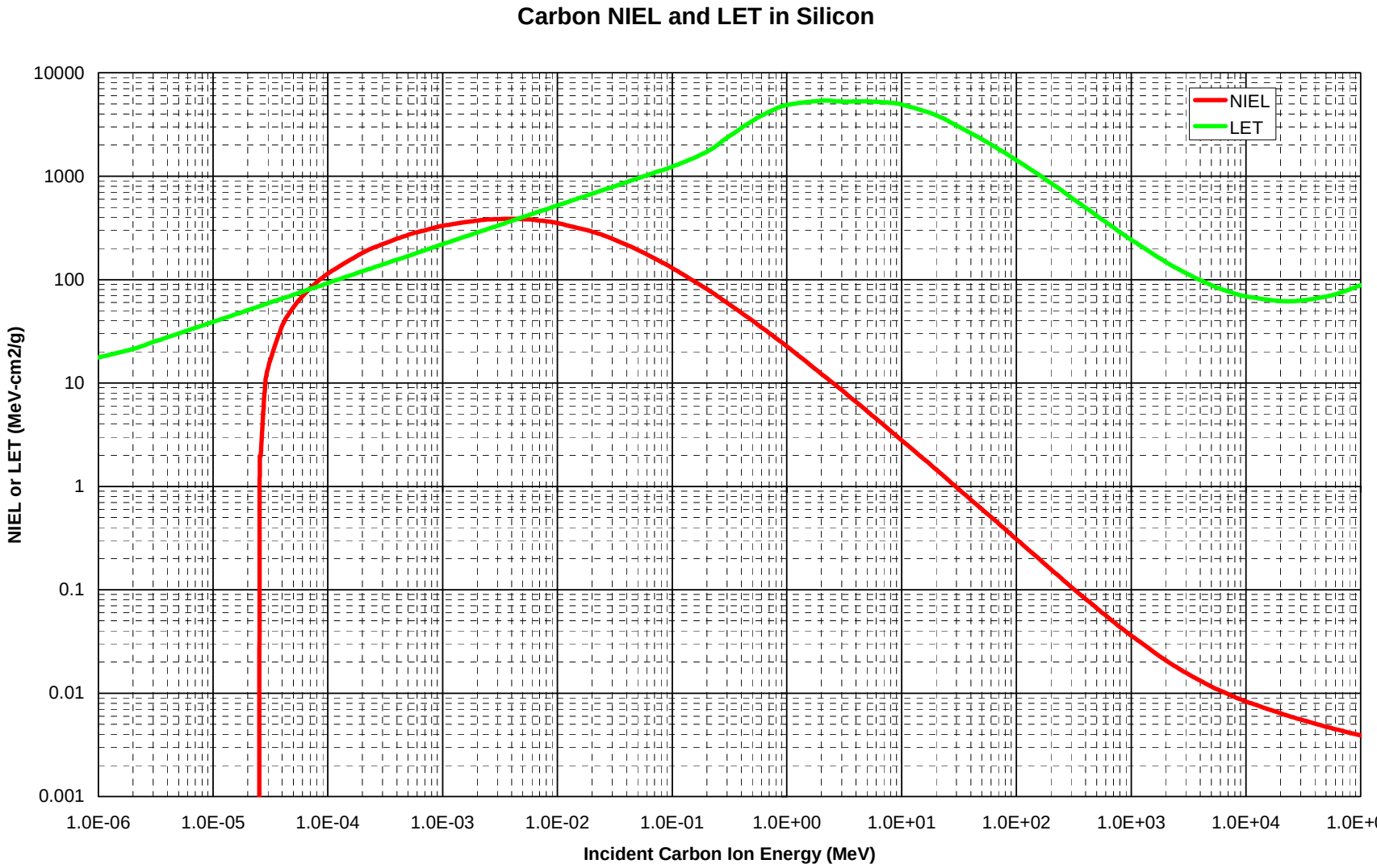




Displacement Damage Models

- **JPL Model for radiation degradation of solar cells**
  - » **Based on experimental data**
  - » **Useful for experimentally well-characterized cells**
- **NRL Model for radiation degradation of solar cells**
  - » **Based on limited experimental data and nonionizing energy loss (NIEL) calculations**
  - » **Useful for characterizing new technologies**
- **WinNIEL Model**
  - » **Provides NIEL values not previously available for wide ranges of particle energies and many solar cell materials**
  - » **Extends utility of NRL Model**

Nonionizing Energy Loss in Silicon



Summary

- **Models covered:**
  - Solar particle events
  - Galactic cosmic rays
  - Trapped particles
  - Displacement damage

- **References:**
  - MSFC SEE Program – http://see.msfc.nasa.gov
  - SPENVIS – www.spenvis.oma.be/spenvis/